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Acetylcholinesterase Activity and Serum Testosterone as Biomarkers in Male Printing Press Workers Exposed to Printing Chemicals within Port Harcourt Metropolis, Rivers State, Nigeria

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ABSTRACT

Printing press workers are routinely exposed to occupational chemicals such as organic solvents, inks, pigments, adhesives, and volatile organic compounds, many of which have been associated with neurotoxicity and endocrine disruption. This study assessed acetylcholinesterase activity and serum testosterone levels among male university printing press workers in Port Harcourt metropolis. A comparative cross-sectional study was conducted among 120 male participants, comprising 90 printing press workers from three universities and 30 apparently healthy non-exposed controls from a university outside the study area. Acetylcholinesterase activity was determined by spectrophotometric method, while serum testosterone concentration was measured using enzyme-linked immunosorbent assay (ELISA). Data were analysed using one-way analysis of variance followed by Tukey's Honestly Significant Difference post hoc test, with statistical significance set at $p < 0.05$. Acetylcholinesterase activity differed significantly among the groups ($F(3,116) = 238.57$, $p < 0.05$), with the lowest mean value observed in University A workers (3.21 ± 0.42 U/L) and the highest in controls (6.12 ± 0.53 U/L). Serum testosterone concentrations also differed significantly ($F(3,116) = 313.84$, $p < 0.05$), ranging from 2.84 ± 0.31 ng/mL in University A workers to 5.76 ± 0.47 ng/mL in controls. The exposed male university printing press workers exhibited significantly reduced acetylcholinesterase activity and serum testosterone levels compared with the non-exposed control group, suggesting that chronic occupational exposure to printing-related chemicals may adversely affect neurological and endocrine function. Regular occupational health surveillance and improved workplace safety measures are recommended.

Keywords: Acetylcholinesterase; Testosterone; Occupational Exposure; Printing Press Workers; Neurotoxicity; Reproductive Health; Endocrine Disruption; Biomarkers; Industrial Chemicals; Occupational Health.

1.0. Introduction

The exposure to chemicals released from industries by printing press workers remains a vital and globally known public health issue. These chemicals are in form of solvents, inks, dyes, volatile organic compounds, and heavy metals [1-3], and are capable of inducing some biochemical [4], neurological [5], and endocrine alterations [6]. Some of the chemicals frequently used during printing operations are benzene, toluene, xylene, formaldehyde, pigments, and hydrocarbon-containing compounds, many of which have significant impacts on human health and the environment [7, 8].

One major enzyme responsible for neurotransmission is acetylcholinesterase (AChE). It carries out this activity through the hydrolysis of acetylcholine at cholinergic synapses [9]. Hence, its inhibition results in accumulation of acetylcholine at nerve endings, leading to impaired neuronal function and neurotoxicity [10]. Several studies have reported that occupational exposure to solvents and industrial chemicals decreases the activities of acetylcholinesterase [11-14]. Besides, the decreased acetylcholinesterase activity has been linked with clinical symptoms like headaches, dizziness, impaired cognition, fatigue, and neuromuscular dysfunction [14, 15].

Testosterone, on the other hand, is a major male reproductive hormone responsible for spermatogenesis, libido, muscle development, and the maintenance of secondary sexual characteristics [16, 17]. Exposure to industrial

chemicals, specifically the endocrine disruptors, may interfere with endocrine regulation and impair testosterone synthesis through several biochemical mechanisms like oxidative damage, disruption of steroidogenesis, and toxic effects on Leydig cells [17-19]. Several studies have also shown that chronic exposure to industrial pollutants and volatile organic compounds may significantly decrease serum testosterone levels among exposed individuals [20].

As a matter of fact, some factors like prolonged working hours, inadequate ventilation, poor use of personal protective equipment, and continuous handling of inks and solvents may enhance the exposure of printing press workers to some occupational chemicals [21, 22], leading to increased occupational health risks.

Despite these occupational health risks, little or no studies have focused on assessing acetylcholinesterase activity and testosterone levels among university printing press workers in Rivers State, Nigeria. Hence, this study was therefore designed to comparatively assess acetylcholinesterase activity and testosterone levels among male university printing press workers in the universities in located in Port Harcourt metropolis.

1.1. Specific Objectives

The main aim of the study is to assess acetylcholinesterase activity and serum testosterone as biomarkers in male printing press workers Exposed to Printing Chemicals within Port Harcourt metropolis, Rivers State, Nigeria. Specifically, the study aims to:

- determine the acetylcholinesterase activity among male printing press workers occupationally exposed to printing chemicals in selected universities within Port Harcourt metropolis, Rivers State, Nigeria compared with the control group.
- ascertain the serum testosterone levels among male printing press workers occupationally exposed to printing chemicals in selected universities within Port Harcourt metropolis, Rivers State, Nigeria compared with the control group.

2.0. Materials and Methods

2.1. Study Area

This study was conducted in the Port Harcourt metropolis, Rivers State, Nigeria.

2.2. Study Design

A comparative cross-sectional study design was adopted to assess acetylcholinesterase activity and serum testosterone levels among exposed male printing press workers and non-exposed control workers.

2.3. Study Population

The study population consisted exposed printing press workers employed in three universities within Port Harcourt metropolis in Rivers State, Nigeria. To ensure institutional confidentiality, the participating universities are referred to as University A, University B, and University C. The control group consisted of apparently healthy male staff recruited from a university without occupational exposure to printing press operations. This group was selected to provide a comparable non-exposed population for evaluating the potential biochemical effects of workplace chemical exposure. All participants were recruited voluntarily after providing written informed consent.

2.4. Sample Size and Sampling Technique

The sample size was determined using Cochran's formula for cross-sectional studies:

$n = Z^2pq/d^2$, where n is the minimum required sample size, Z is the standard normal deviate at the 95% confidence level (1.96), p is the estimated prevalence of occupational chemical exposure among printing press workers obtained from previous studies, $q = 1 - p$, and d is the desired precision (0.05). To increase statistical power and make up for possible non-response, a total of 120 participants were recruited for the study. The exposed group consisted of 90 printing press workers, with 30 exposed participants recruited from each of the three universities, while the control group comprised 30 apparently healthy males recruited from a university outside the study area. Participants were recruited using a purposive sampling technique because the study specifically targeted male university printing press workers with occupational exposure to printing chemicals. All eligible workers who met the inclusion criteria and consented to participate during the study period were invited to enroll for the study.

2.5. Inclusion Criteria

The study included male printing press workers who were 18 years of age or older; had been employed in printing operations for at least one year; and voluntarily consented to participate in the study.

2.6. Exclusion Criteria

Individuals were excluded from the study if they had a known endocrine disorder; were receiving hormonal therapy; were chronic smokers; consumed alcohol excessively; had a history of chronic systemic illness; or declined to provide informed consent.

2.7. Collection of Demographic Information

Important demographic and occupational data, including age, body mass index (BMI), educational level, marital status, duration of employment, smoking history, alcohol consumption, and hormonal therapy status, were obtained using a structured researcher-administered questionnaire. BMI was calculated as weight in kilograms (Kg) divided by the square of height in metres (kg/m^2).

2.8. Blood Sample Collection

Approximately 5 mL of venous blood was collected aseptically from each participant by standard venipuncture. About 2 mL was dispensed into an ethylenediaminetetraacetic acid (EDTA) tube for the acetylcholinesterase assay, while the remaining 3 mL was transferred into a plain tube for serum separation. Serum samples were obtained by centrifugation at 3,000 rpm for 10 minutes and stored at −20°C until biochemical analysis.

2.9. Determination of Acetylcholinesterase Activity

Acetylcholinesterase activity was determined using the spectrophotometric method described by Patlolla and Tchounwou [23]. The assay is based on the enzymatic hydrolysis of acetylthiocholine iodide by acetylcholinesterase to produce thiocholine, which subsequently reacted with 5,5′-dithiobis-(2-nitrobenzoic acid) (DTNB) to form 5-thio-2-nitrobenzoate, a developed yellow-coloured product measurable at a wavelength of 405 nm. Enzyme activity was expressed in units per litre (U/L).

2.10. Determination of Serum Testosterone

Serum testosterone concentration was determined using an enzyme-linked immunosorbent assay (ELISA) kit (Monobind Inc., Lake Forest, CA, USA) according to the manufacturer's instructions. The assay is based on the competitive binding principle, in which testosterone in the sample competes with enzyme-labelled testosterone for binding sites on anti-testosterone antibodies. Following incubation and washing, the enzymatic reaction was developed using tetramethylbenzidine (TMB) substrate, and absorbance was measured at 450 nm using a microplate reader. Testosterone concentrations were calculated from a standard calibration curve and expressed in nanograms per millilitre (ng/mL).

2.11. Statistical Analysis

Data obtained from the study were entered into and analysed using the Statistical Package for the Social Sciences (SPSS) version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. Comparisons among study groups were performed using one-way analysis of variance (ANOVA). Where statistically significant differences were detected, Tukey's Honestly Significant Difference (HSD) post hoc test was used for multiple pairwise comparisons between groups. Prior to ANOVA, data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test. The assumptions for parametric analysis were satisfied. Statistical significance was set at $p < 0.05$.

3.0. Results and Discussion

3.1. Results

3.1.1. Demographic Characteristics of the Study Participants

A total of 120 male participants were recruited for this study, comprising 90 printing press workers and 30 non-exposed controls. The exposed group consisted of 30 workers each from the University A, University B, and University C. The mean age of participants was comparable across the study groups, ranging from 36.8 ± 7.5 years among workers from the University A to 39.2 ± 6.9 years among workers from University C, while the control group had a mean age of 37.4 ± 7.1 years. Similarly, the mean body mass index (BMI) was relatively consistent among the groups, varying from 24.6 ± 2.7 kg/m² to 25.2 ± 3.1 kg/m². Among the printing press workers, the mean duration of employment was 11.8 ± 4.6 years at the University A, 10.5 ± 4.1 years at University B, and 9.7 ± 3.8 years at University C. Regarding educational attainment, the majority of participants in all study groups had tertiary education, accounting for 83.3%, 86.7%, 80.0%, and 83.3% of participants in the University A, University B, University C, and control groups, respectively.

Most participants were married, representing 73.3% of workers from the University A, 70.0% from University B, 66.7% from University C, and 70.0% of the control group. Assessment of occupational exposure duration showed that more than half (56.7%) of the University A workers and half (50.0%) of the University B workers had been employed in printing operations for more than 10 years, whereas 43.3% of University C workers had occupational

exposure exceeding 10 years. None of the participants reported a history of smoking, chronic alcohol consumption, or hormonal therapy use, in accordance with the study's eligibility criteria.

Table 1. Demographic Characteristics of the Study Participants

Variable	University A (n = 30)	University B (n = 30)	University C (n = 30)	Control (n = 30)
Age (years), Mean ± SD	36.8 ± 7.5	38.1 ± 6.7	39.2 ± 6.9	37.4 ± 7.1
Body Mass Index (kg/m²), Mean ± SD	24.8 ± 2.9	25.2 ± 3.1	24.6 ± 2.7	24.9 ± 2.8
Duration of employment (years), Mean ± SD	11.8 ± 4.6	10.5 ± 4.1	9.7 ± 3.8	N/A
Educational level, n (%)				
Secondary	5 (16.7)	4 (13.3)	6 (20.0)	5 (16.7)
Tertiary	25 (83.3)	26 (86.7)	24 (80.0)	25 (83.3)
Marital status, n (%)				
Single	8 (26.7)	9 (30.0)	10 (33.3)	9 (30.0)
Married	22 (73.3)	21 (70.0)	20 (66.7)	21 (70.0)
Years of occupational exposure, n (%)				
1–5 years	4 (13.3)	5 (16.7)	6 (20.0)	N/A
6–10 years	9 (30.0)	10 (33.3)	11 (36.7)	N/A
>10 years	17 (56.7)	15 (50.0)	13 (43.3)	N/A
Smoking history, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Chronic alcohol consumption, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Hormonal therapy, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Results are expressed as mean ± standard deviation or frequency (percentage), as appropriate. BMI = Body Mass Index; N/A = Not applicable.

3.1.2. Acetylcholinesterase Activity among Male University Printing Press Workers

The acetylcholinesterase (AChE) activity of male university printing press workers and the control group is presented in Table 2. One-way analysis of variance (ANOVA) demonstrated a statistically significant difference in mean AChE activity among the four study groups ($F(3, 116) = 238.57$, $p < 0.05$).

Post hoc analysis using Tukey's Honestly Significant Difference (HSD) test revealed that the mean AChE activity of workers from University A (3.21 ± 0.42 U/L), University B (4.05 ± 0.37 U/L), and University C (4.63 ± 0.41 U/L) was significantly lower than that of the control group (6.12 ± 0.53 U/L) (all $p < 0.05$). Furthermore, pairwise comparisons showed that workers from University A had significantly lower AChE activity than those from University B ($p < 0.05$) and University C ($p < 0.05$), while workers from University B also had significantly lower enzyme activity than those from University C ($p < 0.05$).

Above all, these findings indicate a graded reduction in acetylcholinesterase activity among the exposed groups, with the greatest enzyme inhibition observed among workers from University A.

Table 2. Acetylcholinesterase Activity among Male University Printing Press Workers and Control

Study Group	AChE Activity (U/L) Mean ± SD
University A	3.21 ± 0.42*
University B	4.05 ± 0.37*
University C	4.63 ± 0.41*
Control	6.12 ± 0.53

Results are expressed as mean ± standard deviation. *Significant at $p < 0.05$ compared with control group.

3.1.3. Testosterone Levels among Male University Printing Press Workers

The serum testosterone concentrations of male university printing press workers and the control group are presented in Table 3. One-way analysis of variance (ANOVA) demonstrated a statistically significant difference in mean serum testosterone levels among the four study groups ($F(3, 116) = 313.84$, $p < 0.05$).

Post hoc analysis using Tukey's Honestly Significant Difference (HSD) test showed that workers from University A (2.84 ± 0.31 ng/mL), University B (3.42 ± 0.28 ng/mL), and University C (4.01 ± 0.35 ng/mL) had significantly lower serum testosterone concentrations than the control group (5.76 ± 0.47 ng/mL) (all $p < 0.05$). Pairwise comparisons further revealed that testosterone levels in workers from University A were significantly lower than those of workers from University B ($p < 0.05$) and University C ($p < 0.001$), while workers from University B also had significantly lower testosterone concentrations than workers from University C ($p < 0.05$).

Among the exposed groups, workers from University A exhibited the greatest reduction in serum testosterone concentration, whereas workers from University C recorded the highest values among the exposed workers but remained significantly lower than those of the control group.

Table 3. Testosterone Levels among Male University Printing Press Workers and Controls

Study Group	Testosterone (ng/mL) Mean ± SD
University A	2.84 ± 0.31*
University B	3.42 ± 0.28*
University C	4.01 ± 0.35*
Control	5.76 ± 0.47

Results are expressed as mean ± standard deviation. *Significant at $p < 0.05$ compared with control group.

3.2. Discussion

3.2.1. Acetylcholinesterase Activity among Printing Press Workers

The present study demonstrated significant reductions in acetylcholinesterase activity among male university printing press workers compared with the control group. This finding suggests possible occupational neurotoxicity resulting from chronic exposure to industrial solvents, inks, and volatile organic compounds used in printing operations [24]. Similar reductions in acetylcholinesterase activity among occupationally exposed workers have been reported in previous studies involving industrial and chemical workers [23, 25-27].

The reduction in acetylcholinesterase activity may be attributable to inhibition of cholinesterase enzymes by occupational chemicals, resulting in accumulation of acetylcholine at cholinergic synapses and impaired neuronal transmission. In addition, chronic exposure to volatile organic compounds and industrial solvents may induce oxidative stress, lipid peroxidation, and mitochondrial dysfunction, further contributing to neurotoxicity [5, 26-28]. Continuous exposure to hydrocarbon-containing compounds and volatile organic chemicals may lead to accumulation of acetylcholine at synaptic junctions, resulting in impaired neuronal function and neurobehavioral disturbances [29, 30].

Among the universities studied, workers from the University A demonstrated the greatest reduction in acetylcholinesterase activity, followed by workers from University B, while workers from University C exhibited the least reduction. This variation may be associated with differences in printing workload, workplace ventilation, and level of compliance with occupational safety practices [31, 32].

3.2.2. Testosterone Levels among Printing Press Workers

This study also revealed considerably reduced testosterone levels among exposed workers compared with controls. The decrease in testosterone concentration may be due to endocrine-disrupting effects of industrial chemicals and solvents commonly encountered in printing environments [33]. Industrial toxicants have been shown to interfere with steroidogenesis, impair Leydig cell function, and alter hormonal regulation within the hypothalamic-pituitary-gonadal axis [18, 19, 34, 35].

Workers from the University A showed the greatest reduction in testosterone levels, suggesting a higher degree of endocrine disruption compared with workers from the other universities studied [36]. Workers from University C exhibited the least hormonal alteration among the exposed groups.

3.2.3. Public Health Implications

The findings of this study focus on the high rising occupational and public health problems related to long-term exposure to printing chemicals among university printing press workers. Reduced acetylcholinesterase activity may predispose exposed individuals to neurological impairment and poor quality of life, while decreased testosterone levels may predispose exposed individuals to reproductive dysfunction and reduced productivity [37-40]. Hence, the study points out the need for effective public health monitoring.

3.2.4. Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design prevents the setting up of causal relationships between work-related exposure to printing chemicals and the detected changes in acetylcholinesterase activity and serum testosterone levels. Second, quantitative environmental monitoring and biological measurements of specific printing-related chemicals were not performed; therefore, exposure status was deduced from occupational history rather than direct measurement. Although age and body mass index were comparable among the study groups, other potential confounding factors, including dietary habits, environmental exposures outside the workplace, medication use, and genetic susceptibility, were not evaluated and may have influenced the observed findings. Furthermore, the relatively modest sample size and recruitment of participants from selected institutions may limit the generalisability of the results to all printing press workers. Hence, future longitudinal studies incorporating direct exposure assessment, larger multicentre populations, and adjustment for additional confounding variables are recommended to confirm and extend these findings.

4.0. Conclusion and Future Recommendations

This study showed noteworthy reductions in acetylcholinesterase activity and testosterone levels among male university printing press workers in Port Harcourt compared with the non-exposed control group. Workers from the University A were the most affected, followed by workers from University B, while workers from University C exhibited the least biochemical changes. The notable reductions in acetylcholinesterase activity and serum testosterone concentration may point towards the effects of chronic occupational exposure to printing chemicals among university printing press workers. Future studies should:

- conduct longitudinal studies to establish causal relationships between chemical exposure and adverse health effects;
- involve larger, multi-centre populations to enhance the generalisability of the findings;
- assess additional biomarkers of oxidative stress, endocrine disruption, and genotoxicity for a more detailed health assessment;
- investigate the effectiveness of occupational health interventions, including personal protective equipment, engineering controls, and worker education; and
- determine the dose–response relationships through comprehensive environmental and biological exposure surveillance.

Declarations

Source of Funding

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Competing Interests Statement

The authors have declared that no competing financial, professional or personal interests exist.

Consent for publication

All authors contributed to the manuscript and consented to the publication of this research work.

Availability of data and material

Supplementary information such as the raw files is available from the authors upon reasonable request.

Ethical Approval

Ethical approval was obtained from the Rivers State University Research Ethics Committee (Approval No. RSU/FBMS/REC/2026/541) before the commencement of the study.

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Declaration of Artificial Intelligence

The authors declare that artificial intelligence (AI)-assisted tools (Grammarly and Quillbot) were used solely to improve the language, grammar, clarity, and overall presentation of this manuscript. All scientific content, study design, data collection, data analysis, interpretation of results, and final conclusions were conceived, verified, and approved by the authors. The authors accept full responsibility for the accuracy, integrity, and originality of the work.

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